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Original Research Paper

Source apportionment of the sediments entering dam using lithological and mineralogical studies

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ABSTRACT: The present study was carried out to determine the possible origins of sediments entering Taleghan Dam in northern part of Iran, in order to avoid further sedimentation and helping in extension of the useful life of the proposed dam. This was performed by XRD analysis. To do so, first of all, sediment sampling points were positioned along the Taleghan River. The collected samples, after coding, were transferred to the laboratory for mineralogical testing. Then, the samples were exposed to X-ray diffraction analysis. The experimental results were compared with data from geology, land cover land use and slope maps in order to find the possible primary origins of deposits in the Taleghan Dam. Furthermore, the geological formations and physiographical parameter such as slope were also analyzed to test erodibility of the formations. The results showed that most sediment samples in Taleghan are of sedimentary sandstone, mainly containing the quartz and plagioclase minerals (quartz sandstone and arkose sandstone). The findings also showed that calcite and dolomite were abundant in the collected samples, while aragonite and anthracite were found to a lesser extent in the samples. Accordingly, acidic and alkaline formations, mudstone, and siltstone of Karaj area formations, the gypsum of upper red formation, particularly at places with steep slope with a dominance of rangeland land use type, are main origins of sediments in the Taleghan reservoir. In another hand, the control of sediments at these areas would substantially decrease total sediment yields of the entire basin as in the dam reservoir.

KEYWORDS: *Erodibility; Mineralogy; Sediment; Slope; Taleghan Dam; X-ray powder diffraction (XRD)*

INTRODUCTION

Recently, the rate of soil erosion has been accelerated due to human intervention. This can lead to numerous adverse effects on the environment such as declined water quality of surface water, increased sedimentation load in the reservoirs, and transport of contaminants in the environment as a source of pollution (Velegrakis *et al.,* 2008; Sharma and Singh 2014; Frémion *et al.,* 2016; Lu *et al.,* 2015). Increased rates of sediment production in catchment areas can affect adversely the quality and quantity of drinking and agriculture water resources. It can also reduce soil permeability, resulting in increased runoff and ultimately increases the destructive power of floods at downstream areas. Another negative effect of sedimentation would be a reduction in the productivity, which will ultimately lead to yield loss in crops. One of the negative effects of increasing and accelerating the sedimentation process, especially from economic and environmental standpoints, can be early filling the reservoirs that shortens useful life of dams, substantially (Huffaker and Hotchkiss, 2006; Palmieri *et al.,* 2001; Heidarnejad *et al.,* 2006; Biba., 2012). Thus, it would be of utmost concern to identify and control source areas of soil loss upstream of dams and reservoirs (Sprague and Sprague, 2016; Green 2013; Wang *et al.,* 2004).

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Identification of the causes of sedimentation, followed by timely and efficient management to reduce erosion and soil loss, as well as reducing transport of corrosive materials to the mouth of rivers will play a quite effective role in controlling sediment entering reservoirs and increasing shelf life of dams (Behrangi *et al.,* 2014; Issa *et al.,* 2016). Generally speaking, sedimentation is affected by the process of erosion and soil loss at sediment sources in the upstream catchments and transfer of the eroded materials from the moment of separation up to the deposition at the outlet of watersheds (Andredaki *et al.,* 2014; Whitney *et al.,* 2015; Dotterweich *et al.,* 2012; Umar *et al.,* 2015). The phenomenon of sedimentation is more complicated and influenced by several factors such as sediment density, type of sediment particles, topographical conditions of the region, sensitivity of soils and stones to erosion, type of land use and management operations at the basin level, intensity and frequency of rainfall. However, it is affected directly from natural conditions and human activities. Transfer of soil sediment towards the lowlands comprises an important part of global geochemical cycle of elements (Walker, 1986).

As such, estimates show that a large proportion of elements such as phosphorus, nickel, manganese, chromium, lead, iron, and aluminum are usually displaced by suspended sediment of rivers, although the proportion varies depending the type of soil or industries in the upstream areas (Ludwing *et al.,* 1996). There are several ways to estimate suspended sediment load of rivers. One of the most commonly-used methods is X-ray powder diffraction (XRD), which is used to determine the material and type of sediment behind dams and rivers (Fryirs and Gore, 2013; Kinouchi *et al.,* 2012; Hillier 2001, Ryan *et al.,* 2002). This technique can be used to apportion sources of sediments transferred by rivers and streams. Many case studies exist on the use of these methods for sediment tracking purposes. Frémion *et al.,* (2016) studied physicochemical features of a total number of 25 sediment samples taken from Vaussaire Catchment in Cantal, France. Their findings revealed that the dam is strongly influenced by the grain sized organic matter. Howell *et al.* (2014) used sediment cores and geophysical data to determine the time, pathways, and sources of sediment entered to a muddy shelf-slope depositional system in Pandora Trough and Gulf of Papua. They found that the fluvial sediments of the muddy inner shelf well match with the geological structure of the Lakekamu and Vailala catchments. Gougazeh and Al-Shabatat, 2013 used XRD technique to apportion sediments delivered to Tannur Dam in South Jordan. They reported that the landslide materials were mainly composed of smectite including minor amounts of calcite and quartz, while the alluvium materials were mostly composed of quartz, calcite and smectite. Benedetti *et al.,* (2013) studied floodplain deposits in the basin of Cape Fear River in North Carolina to track the sources of downstream alluvium originating from Piedmont and Coastal Plain. They could indicate that sand in the estuary mainly included quartz, while fine sediment consisted of fairly diverse minerals most resembling the piedmont-draining rivers. Shia *et al.* (2014) detected sediment pollution Mianyuan River in China to the heavy metals. According to their results, the origin for the Cd, Se, and As in the riverbed sediments were geogenic, and for Cr, Zn, Ba, and Mn were anthropogenic. In a research by Frihy *et al.* (2014) in Nil Delta littoral system it was found that magnetite, ilmenite, hematite, leucoxene, garnet, zircon, and rutile were predominant in the heavy mineral grades.

Dams as water storage structures are of vital importance, particularly in arid and semi-arid countries like Iran. In proportion to the importance of these structures, it is required to protect them in a way that their performance does not decline over time. Sedimentation is one of the serious threats to dams. With increased sedimentation in dams, their storage capacity is gradually filled up, causing poorer water quality. Therefore, it is essential to identify and control the origin of sediments in order to avoid reducing the efficiency of dams and compromising the quality of water. This study was conducted to detect the sources of the sediments delivered to Taleghan Dam in northern Iran during 2014-2015.

MATERIALS AND METHODS

Study area

Taleghan Basin is situated between 36°05'17.45"–36°20'45.93" northern latitudes and 50°39'33.39"–51°11'26.5" eastern longitudes (Kheirkhah Zarkesh *et al.,* 2010) (Fig. 1). As a mountainous region with steep slopes, the basin is highly prone to erosion. The average annual precipitation in the basin is estimated to be 871 m3/km2/y cubic meters (Afshar *et al.,* 2016) and the mean annual runoff is 11.75 m3/s (Hosseini *et al.,* 2012). Fig. 1 provides a schema on the location of Taleghan Basin in Iran. In April 2002, construction of

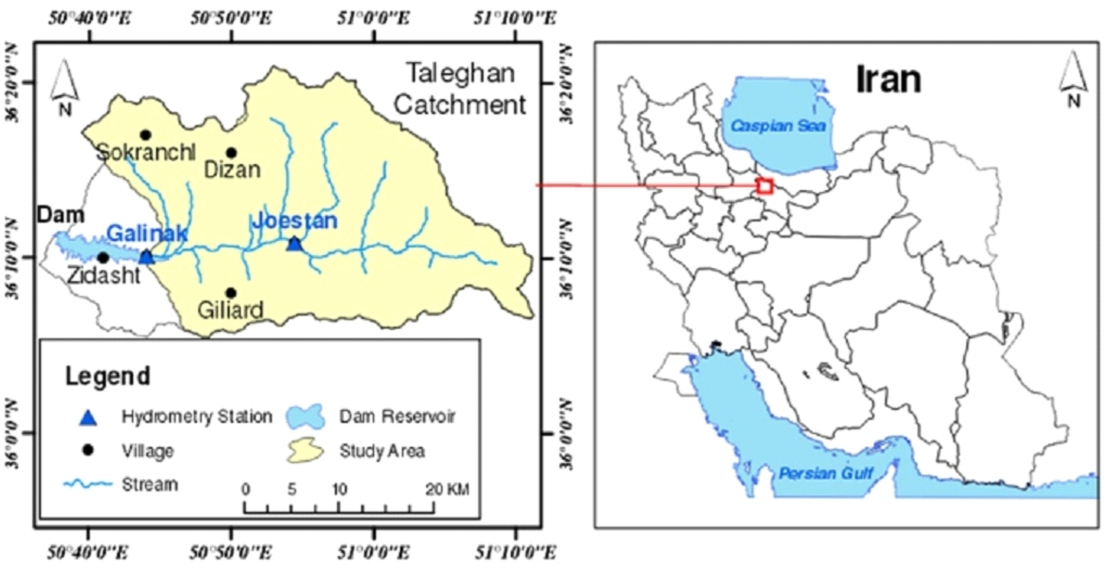

Fig. 1: A schema on the location of Taleghan Dam in Taleghan Basin and in Iran (Hosseini *et al.,* 2012)

Table 1: Technical specifications of Taleghan Dam reservoir (Farajzadeh *et al.,* 2014)

Type of dam	Soil with clay core
Crest elevation	1789 m above the sea level
Height above river bed	103 m
Height above foundation	109 m
Crest length	111 m
Crest width	12 m
Body size	14.8 m m^3
Type of spillway	Open chute
capacity of spillways	2500 m^3
Watershed area	960 km^2
Average annual rainfall	615 mm
Average annual discharge of Taleghan River	16.3 m^3/s
Maximum elevation of reservoir water level	1780 m above the sea level
Reservoir volume	420 mm^3
Useful volume of reservoir	329 mm^3
Reservoir area	12.0 km^2
Total annual discharge	460 mm^3

Taleghan Reservoir began and came into operation in 2006. Table 1 gives technical specifications of Taleghan Dam reservoir.

Research procedure

Step I: preparation of map layers

As two factors influencing deposition in the region, the maps of land use land cover and geology of the Taleghan Basin were prepared. The slope map of the basin was generated from ASTER digital elevation model (DEM) with a pixel size of 30 m. The map of geology was prepared from Geological Survey Organization of Iran at the scale of 1:250000. The land use land cover map of the study area was prepared using supervised classification method (maximum likelihood algorithm) from Land sat satellite image of the year 2013. In order to geometric correction of the images, the topographic map of the basin was also obtained from Geographical Survey Organization of Iran at the scale of 1:250000. The coordinate system of the image was set on universal transverse mercator (UTM), zone 39, north WGS 84. Different land use classes on the images were detected by the use of a total number of 10 ground control points well-

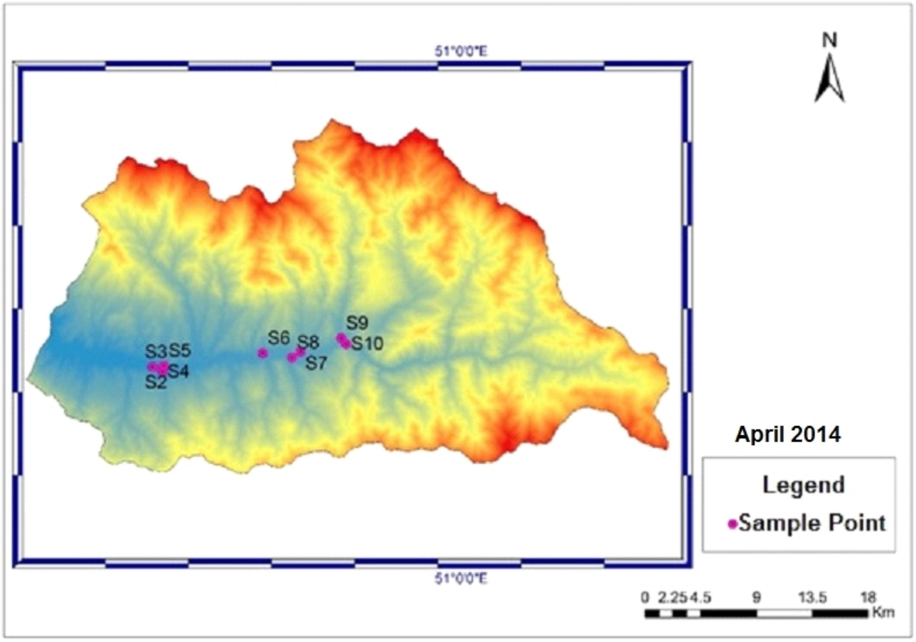

Fig. 2: spatial position of sediment sample points in Taleghan Basin

distributed in the study area. After pre-processing of the image, it was classified in dominant land uses as rangelands, orchards, farmlands, and urban areas. The overall accuracy of 71% and the Kappa coefficient of 0.61 approved the accuracy of classifications and generated land use land cover map.

Step II: laboratory analysis

In this research, in order to detect possible origins of sediments entering the Taleghan Dam, XRD analysis was conducted. To do so, first of all, sediment sampling points were positioned along the Taleghan River. The collected samples, after coding, were transferred to the laboratory for mineralogical testing. At the laboratory, the samples were exposed to X-ray diffraction analysis. This method is used to study the structure of crystalline materials. The X-ray region of the electromagnetic spectrum is within the range between ” and ultraviolet. With this spectral region it can be possible to obtain information about the structure, material, and concentration of elements. For a pure substance, the diffraction pattern of X-ray would be the same as a fingerprint for that substance. The experimental results were compared with data from geology, land cover land use, and slope maps in order to find the possible primary origins of deposits in the Taleghan Dam.

RESULTS AND DISCUSSION

XRD analysis

In this research in order to track the origins of sediments deposited behind the Taleghan Dam, 10 samples were taken from downstream of the reservoir and along Taleghan River. The distribution of sampling pints is depicted in Fig. 2. The samples were harvested along the main river of the basin at the confluence of the tributaries to the main river, where there is the greatest possibility of sediment entry from the basins of the upstream. As the figure suggests, sampling points were positioned along Taleghan River at the intersection of the river and the sub-basins.

The samples, coded as S_1 to S_{10}, were sent to the Mineralogy Laboratory for XRD analysis in order to specify the mineralogical ingredient of the samples. The results of laboratory test are given in Figs. 3 and 4, as well as the Table 2.

The results of mineralogical tests revealed that sample 8, coded as S_8, mainly includes quartz, albite, and calcite minor minerals. Orthoclase, dolomite, chlorite, and hematite are four major minerals found in S_8 while mica and illite compose ingredients of trace minerals in this sample. Calcite, analcime, illite, microcline are the only trace minerals found in samples 5, 2, 4, and 1, respectively. Samples 5 and 2 are the

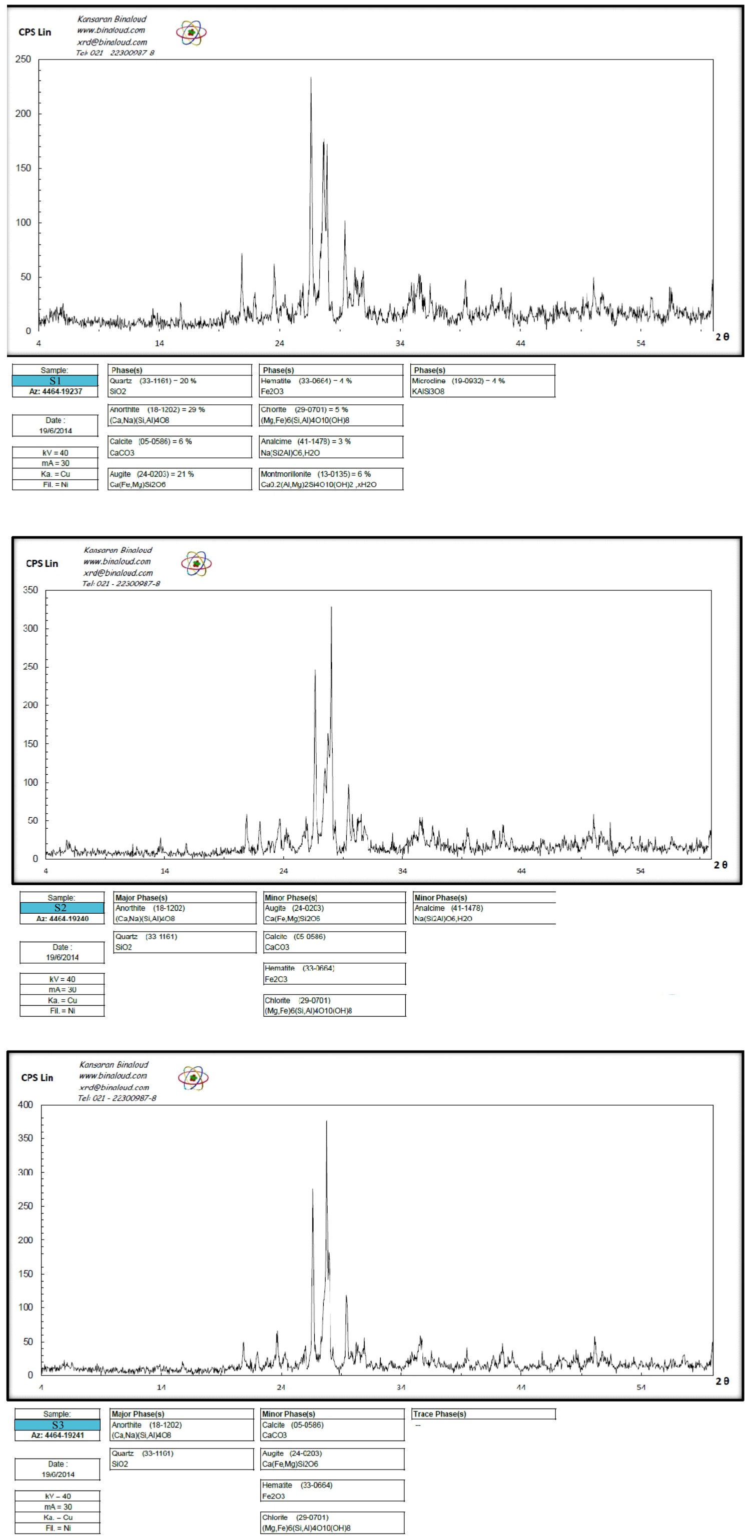

Fig. 3: XRD graphs for some of the samples

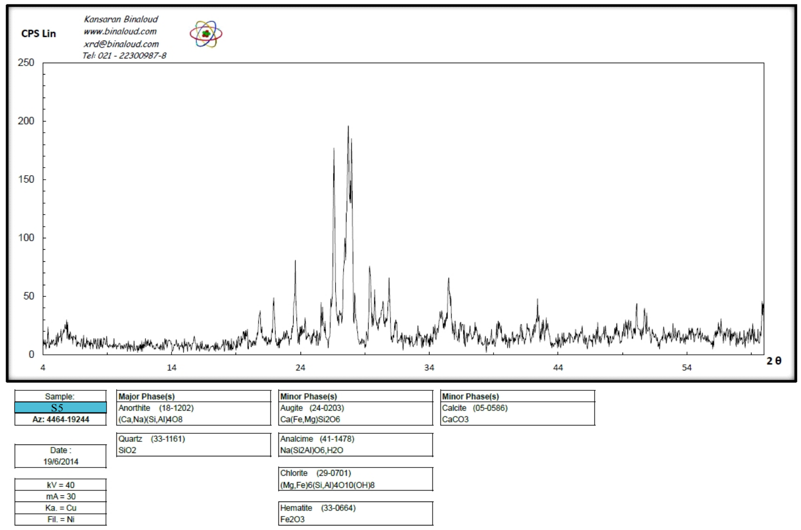

Fig. 3(continue): XRD graphs for some of the samples

Table 2: minerals found in the sediment samples of Taleghan Basin (Afshar *et al.,* 2016)

Sample number	Minor minerals	Major minerals	Trace minerals
S8	Quartz, albite, calcite	Orthoclase, dolomite, chlorite, hematite	Mica, illite
S5	Anorthite, quartz	Augite, analcime, chlorite, hematite	Calcite
S2	Anorthite, quartz	Augite, calcite, hematite, chlorite	analcime
S10	Anorthite, quartz, dolomite, augite	Hematite, chlorite, calcite	-
S9	Anorthite, quartz, calcite, augite	Hematite, chlorite, microcline	-
S4	Quartz, albite, calcite, dolomite	Orthoclase, hematite, chlorite	Illite
S1	Anorthite, quartz, calcite, augite	hematite, chlorite, analcime, montmorillonite	Microcline

same in terms of the composition of minor minerals, both include anorthite and quartz. Hematite, chlorite, and calcite are three major minerals detected in samples 2 and 10. The S8 is the only sample contains dolomite major mineral. Hematite and chlorite are available almost in all of the samples while montmorillonite is only element exclusively found in the sample 1. Table 2 reveals further details of mineralogical composition of the samples.

Fig. 4 illustrates percent of trace, minor, and major minerals in the sediment samples of Taleghan Basin. The greatest proportion of major minerals, with a percent of 81, was found in sample 10. With a very slight difference of 1%, S5 and S8 were ranked next. The smallest proportion belongs to the sample 9 containing 65% of major minerals. Samples 1 and 4, with a percent of 18 and 17, include the greatest preparation of minor minerals, respectively. No trace mineral was found in the samples 9 and 10. Trace minerals include 6% of the total mineralogical composition of the Sample 4. In other words, this sample contains the highest amount of trace minerals.

According to the test results, most of the samples are of sedimentary sandstone. Given the higher proportion of quartz and plagioclase minerals, sandstones would be of quartz and arkose types. In general, rocks known as arkose include more than 25% feldspar, larger amounts of quartz, and some crumbs. Arkose originate from granite and gneiss. They vitiate from sandstones resulting from in-situ weathering, which have suffered little surface transportation, to sandstones with diagonal stratification, which have endured long surface transportation. Among these minerals, calcite and dolomite were abundant in the collected samples, while aragonite, anthracite, and were found to a lesser extent. The abundant presence of quartz and plagioclase is also apparent in microscopic sections of the samples (Fig. 5).

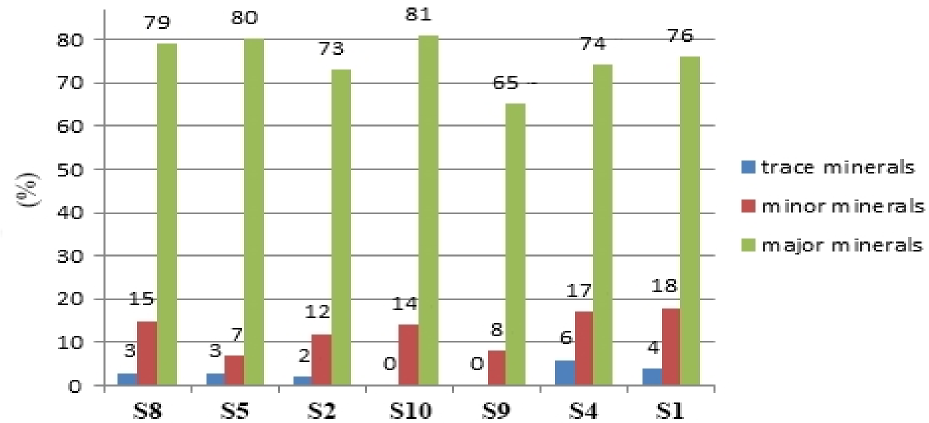

Fig. 4: percent of trace, minor, and major minerals in the sediment samples of Taleghan Basin

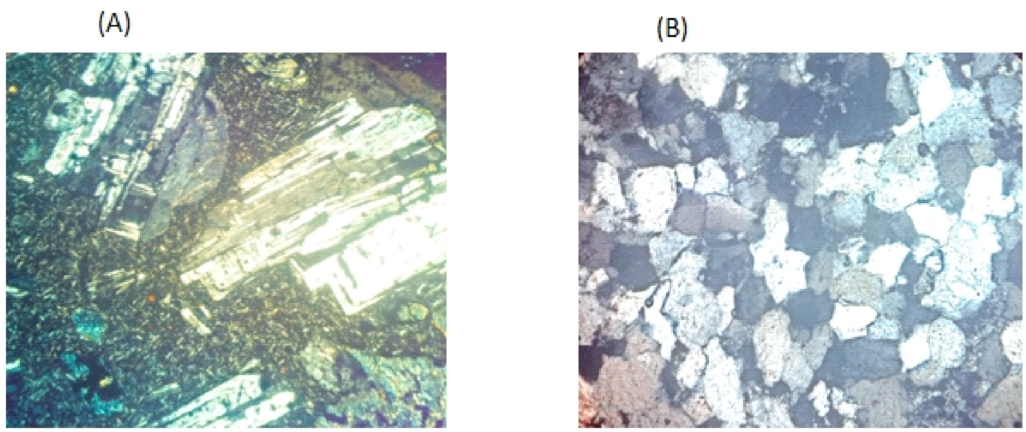

Fig. 5. Two samples of microscopic sections of the sediment samples in Taleghan Basin (A) plagioclase (anorthite), (B) quartz

Inflectional factors on sedimentation

As is clear, there are a variety of factors affecting depositions behind dams. Fig. 6 illustrates maps of slope, erosion, geology, and land use land cover of Taleghan Basin, as four influential factors on sedimentation rate in Taleghan Dam. Slope is one of the most influential factors on sedimentation rate in the basin. In general, steep slopes cause increased sediment yield and facilitate transfer of sediment towards the plains. According to the slope map in the Figure 6, formations in the study area have been classified based on the slope gradient from high to low. As the figure shows, steep slopes characterize the topography of the study. Moving towards the eastern parts, the gradient tends to be steeper up to 50%. Taleghan Basin is considered one of the most erosion prone yields high rate of sediment. According to the recent estimates on soil erosion and sediment yield in Taleghan basin, the amount of special deposition in the basin reaches to 10.2 tons per hectare per year of suspended sediments. Taking 30% of the sediment as the bed load, the total amount of sediment yield in the basin will be equal to 969000 tons (equivalent to 646000 cubic meters). Including the specific gravity of the sediments, it will be tantamount to approximately 1.3 tons per cubic meter. According to the erosion map of the Taleghan Basin, the primary origins of the carbonate sediments were recognized to be limestone and dolomite of Karaj formation. Furthermore, the Precambrian and Paleozoic formations were other possible origins for the sediment in the basin. Table 3 lists the name of formations to the order of the possibility of being origin.

Geological analysis in the area of Taleghan showed that the layers of the earth's crust belong to Precambrian, Paleozoic, Jurassic, Triassic, Cretaceous,

Table 3: Name of formations in Taleghan Basin and the levels of sensitivity to erosion

No.	Formation Name	Resistance against erosion	Lithological features
1	Q	Extremely poor	Quaternary deposits
2	P_r	Poor	Gray to dark gray limestone and sometimes dolomite, and clay or silt layers in the upper parts
3	gy1	Moderate to poor	Gyps and gypsum mudstone
4	gy2	Moderate to poor	Gyps and gypsum mudstone
5	?om	Moderate to poor	Limestone, dolomite , sandstone, and shale; mainly gray-colored
6	Ngm	Moderate	red mudstone and siltstone, sometimes as sandy
7	Etka	Moderate	Mainly acidic tuffs
8	Ngc	Resistance	Conglomerate and red to purple Breccia
9	Ekv	Highly resistance	Mainly alkaline lava
10	V_p	Highly resistance	Basanite

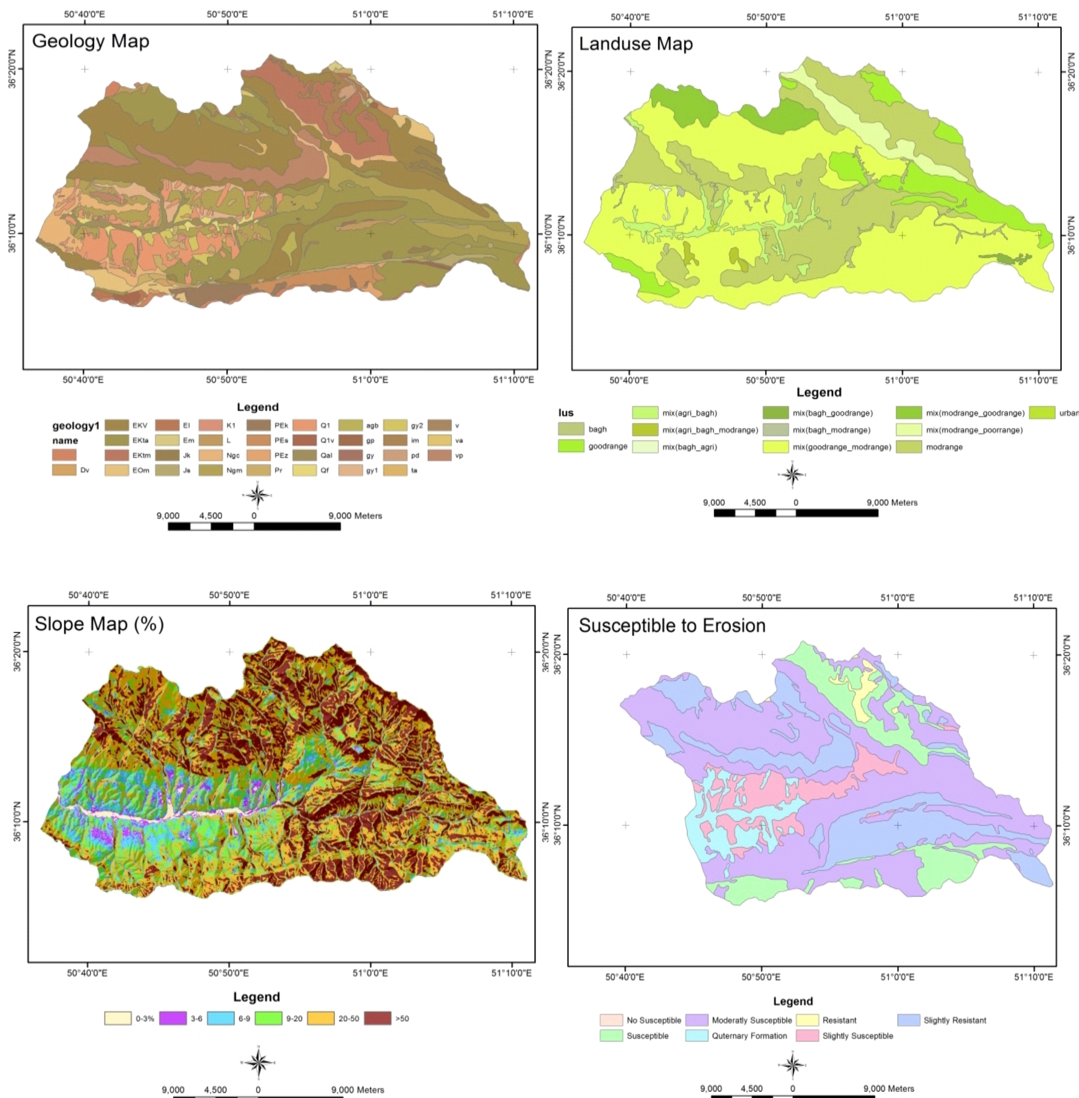

Fig. 6: Maps of geology, slope, erosion, and land use land cover of Taleghan Basin, as four influential factors on sedimentation rate in Taleghan Dam

Pliocene, Paleogene, Neogene, Pliocene, and Quaternary periods, which consists of Kahar, Soltanieh, Barout, Zaguon , Mileh, Laloun, Giroud, Mobarak, Droud, Shemshak, Lar, Tizkouh, Karaj, higher Ghermez, and Quaternary deposits (Afshar *et al.,* 2016). Lithological units in the study area include limestone, dolomite, sandstone, diabase, sandstone, shale, fossiliferous marl, tuff and shale, green tuff, alkaline agglomerate, conglomerate and tuff, analcime basanite, alkaline lavas, and red conglomerates. Geology of the study area mainly consists of volcanic rocks of Karaj Formation and Ngc stones (resistant sandstone, limestone conglomerate Breccia), Ngm (fine-grained calcareous marl), gy2 (marl with gypsum mineral and high amounts of salt) and gy1 (marl with gypsum minerals and low to moderate amount of salt) (Afshar *et al.,* 2016). According to the land use land cover map of the basin, rangelands and farmlands are two main land uses in the study area. Farming in steep slopes would be an inclinational factor accelerating the sediment yield in the study area.

CONCLUSION

Mineralogical analysis of sediment samples in Taleghan Basin revealed that the samples are of sedimentary sandstone. Higher proportion of quartz and plagioclase minerals in the sandstones is an indication of quartz and arkose stones. The analysis also indicated that, calcite and dolomite were abundant in the collected samples, while aragonite and anthracite were found to a lesser extent in the samples. According to which, acidic and alkaline formations, mudstone, and siltstone of Karaj Formations, the gypsum of upper red formation, particularly at places with steep slope with a dominance of rangeland land use type, are main origins of sediments in the Taleghan reservoir. Thus, the control of sediments at these areas would substantially decrease total sediment yields of the entire basin as in the dam reservoir.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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